APPENDIX F.
Determination of the Hydrologic Period for Model Application

Section 6.1.1 defined the hydrologic period for application of the suite of Chesapeake Bay models and reported that the 10-year period 1991-2000 was selected based on a number of criteria. This appendix documents the analyses behind the selection of the hydrologic averaging period.

The hydrologic period for modeling purpose represents a typical long-term hydrologic condition for the water body. The hydrologic period is used for the expression of average annual loads from various sources. It is not to be confused with the critical period which defines a period of high stress (see Section 6.1.2 and Appendix G). It is important that the selected hydrologic period is representative of the long-term hydrology in each area of the Chesapeake Bay watershed so that no particular area is modeled with a particularly high or low loading or an unrepresentative mix of point and nonpoint sources. The selection of a representative hydrologic averaging period ensures that the balance between point and nonpoint source loading and the balance between different geographic areas are appropriate.

Due to the long history of stream flow and water quality monitoring in the Chesapeake Bay watershed, the Chesapeake Bay Program partners were in the position of selecting a time period for model application representative of typical hydrologic conditions from among the 21 contiguous model simulation years – 1985 to 2005. This appendix presents the selection process. The partners first selected ten years as the appropriate number of years for the hydrologic period and then selected the best contiguous ten-year period.

Methods

Monitored stream/river flow was used exclusively as the indicator of hydrology. Three other criteria were investigated but were not used.

1. Rainfall: Stream/river flow was judged to be a better overall indicator than rainfall as flow integrates the effects of evapotranspiration and snowpack effects of temperature. Flow is also more tractable to work with as the nine river input monitoring stations characterize flows and pollutant loads from 80% of the Chesapeake Bay watershed whereas there are approximately 500 rainfall stations across the entire Chesapeake Bay watershed.

2. Water quality: Observed water quality was considered as an ancillary criterion, but was eventually rejected. Observed water quality is dependent, in part, on management actions taken throughout the Bay watershed. The Chesapeake Bay Program's Water Quality Goal Implementation Team decided that the criteria for selecting the hydrologic period should be independent of management actions.

3. Modeled loads: the EPA Chesapeake Bay Program Office performed an analysis of modeled loads to investigate the change in the fraction of load by major river basin and pollutant loading source sectors for different hydrologic averaging periods. This criteria

was also rejected by the Water Quality Goal Implementation Team since it incorporated the effects from management actions and not just hydrology.

The objective of selecting a hydrologic period is to ensure that the relative loads between point and nonpoint sources and between different areas of the Bay watershed are appropriate. The overall criterion was that the hydrologic period have flow statistics that were representative of the long term flow statistics and that this representativeness held across different areas of the Bay watershed. Flow statistics for periods of different length and different starting years were considered. To judge the overall representativeness, several statistics were calculated.

1. Mean flow anomaly: The absolute value of the difference between the mean flow value for any given time period and the long term mean, divided by the long term mean. If the mean flow value for a candidate period were equal to the long term mean, the value of this indicator would be zero. If the mean flow value for a candidate were either zero or twice the long term mean, the value would be one.

2. Standard deviation anomaly: Similar to the mean anomaly, this statistic is the absolute value of the difference between the standard deviation of a candidate period and the long term standard deviation divided by the long term standard deviation.

3. Kolmogorov-Smirnov (K-S) test statistic: The K-S test is a common nonparametric method of comparing two distributions. The cumulative frequency distributions of two populations are plotted together and the maximum distance between the two distributions on the probability axis is used at the test statistic, commonly known as D. From this test statistic, P-values are generally calculated and hypothesis tests run. In the analyses for selecting the hydrologic period, a candidate period distribution is compared to a long-term distribution. For this work, the Water Quality Goal Implementation Team decided to use the D statistic. The D is monotonically related to the P-value in this case since the number of observations was constant across analyses and the distribution of the D-values was more suited to this work. The D-statics was calculated for the daily flow for an estimate of the agreement in short-term events and also for the annual flow for an estimate of the agreement in inter-annual variability.

The nine river input stations comprise the set of farthest-downstream well-monitored flow stations on significant rivers flowing to the Chesapeake Bay. The analysis used a 30-year flow that was common to all nine stations and also a long-term flow that used different flow lengths for each major river basin (Table F-1). In both analyses, only years without missing data were used. At the time of this analysis, the last full year was 2006, so the 30-year analysis used all data from 1977-2006.

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Table F-1. Nine major Chesapeake Bay river flow gage stations used in the determination of the Chesapeake Bay TMDL hydrologic period.

Gage ID	Flow Gage Station Description	Full years in 30-year record	Full years in long-term record
1668000	Rappahannock River near Fredericksburg, VA	30	99
1646502	Potomac River (Adjusted) near Washington, DC	30	77
2037500	James River near Richmond, VA	30	72
1674500	Mattaponi River near Beulahville, VA	28	64
1673000	Pamunkey River near Hanover, VA	30	65
1491000	Choptank River near Greensboro, MD	30	60
1578310	Susquehanna River at Conowingo, MD	30	40
2041650	Appomattox River at Matoaca, VA	30	37
1594440	Patuxtent River near Bowie, MD	29	29

Selecting the Number of Years

Ten years was selected as an appropriate length of time as the following analysis showed that most of the analyzed 10-year periods are statistically similar to the long-term flow record.

To reduce the dimensionality of the analysis, the Water Quality Goal Implementation Team recommended use of a statistic that combined the mean and standard deviation of a given candidate period compared to the same statistics for the 30-year period. The combined statistic allows depiction of a single statistic rather than multiple statistics for easier interpretation. The combination statistic was simply the average of the mean flow anomaly and the standard deviation anomaly described above. The flow and standard deviation anomalies were calculated separately for each of the nine river stations and then averaged. Lower values of the combined statistic correspond to more representative time periods.

Given that the hydrologic period had to be within the Chesapeake Bay model simulation period of 1985-2005, only periods that fell within that 21 year window were considered. The combined statistic was calculated for each instance of each window length that occurred within the modeling period. For example, the statistic was calculated for two 20-year periods, 1985-2004 and 1986-2006 and for 16 6-year period, 1985-1990, 1986-1991, . . . 2000-2005. For each candidate hydrologic period length, the minimum, maximum, and average values of the combined statistic were tabulated and plotted in the Figure F-1.

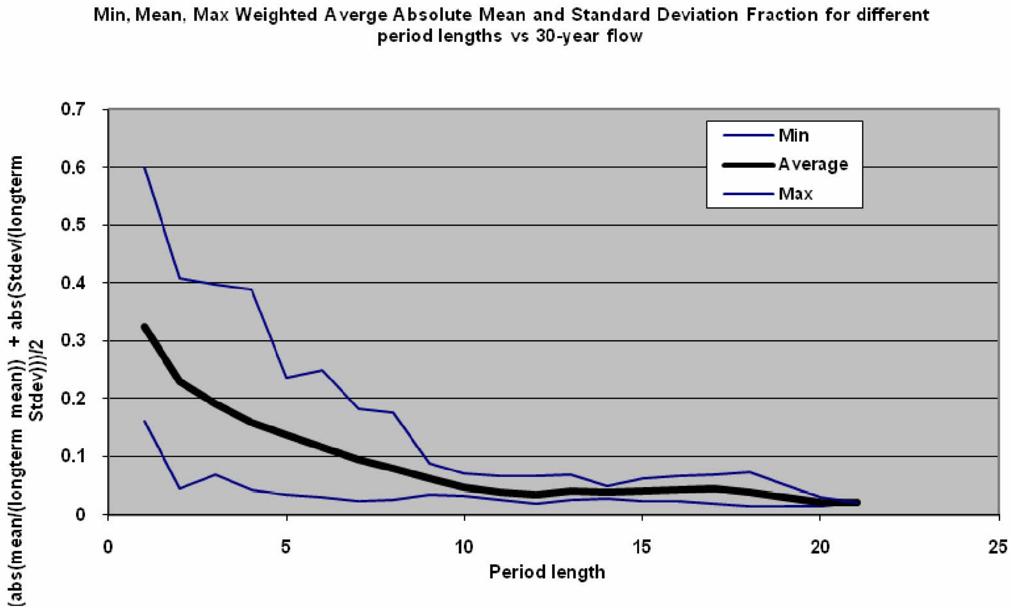


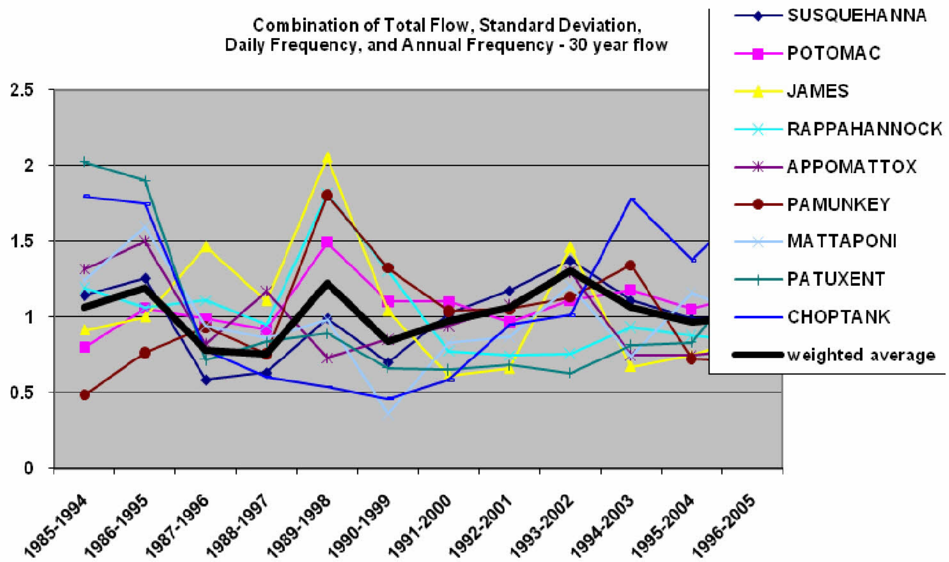
Figure F-1. Range of values of the combined flow statistic for different period lengths.

Figure F-1 illustrates that when using ten or more contiguous years, all possible candidate periods are score relatively well using this combined metric. With fewer than ten years there is a mix of periods that score well and periods that score poorly. A ten year period was chosen by the Water Quality Goal Implementation Team as a robust choice for length of hydrologic period.

Selecting the Ten-Year Period

There are twelve possible ten-year contiguous periods from 1985-2005. Although the above analysis suggests that any of these period may be acceptable, a more detailed analysis showed that there were some regional differences and overall statistical differences between the candidates. As with the selection of the number of years, a combined statistic reduced the dimensionality to make the analysis more tractable. For this analysis, the Water Quality Goal Implementation Team agreed on the development of a statistic that combined mean anomaly, standard deviation anomaly, and the D-statistic for daily and annual flow. These four statistics were normalized by the average value of each statistical type individually and then averaged so that the overall score for all 10-year periods centered around one. These averages were plotted separately for each of the nine major river basins.

For example, the mean anomaly in the James River basin for 1985-1994 was divided by the average mean anomaly of all twelve ten-year periods in the James River basin. The standard deviation anomaly and D-statics for the 1985-1994 were divided by the average of their counterparts for all twelve ten-year periods. These four values were averaged to get an overall score for 1985-1994 in the James River basin. This process was repeated for each basin and also for the flow-weighted average of all nine major river basins for each candidate period. Both the 30-year flow and the long-term flow were considered. The results are shown in Figure F-2.



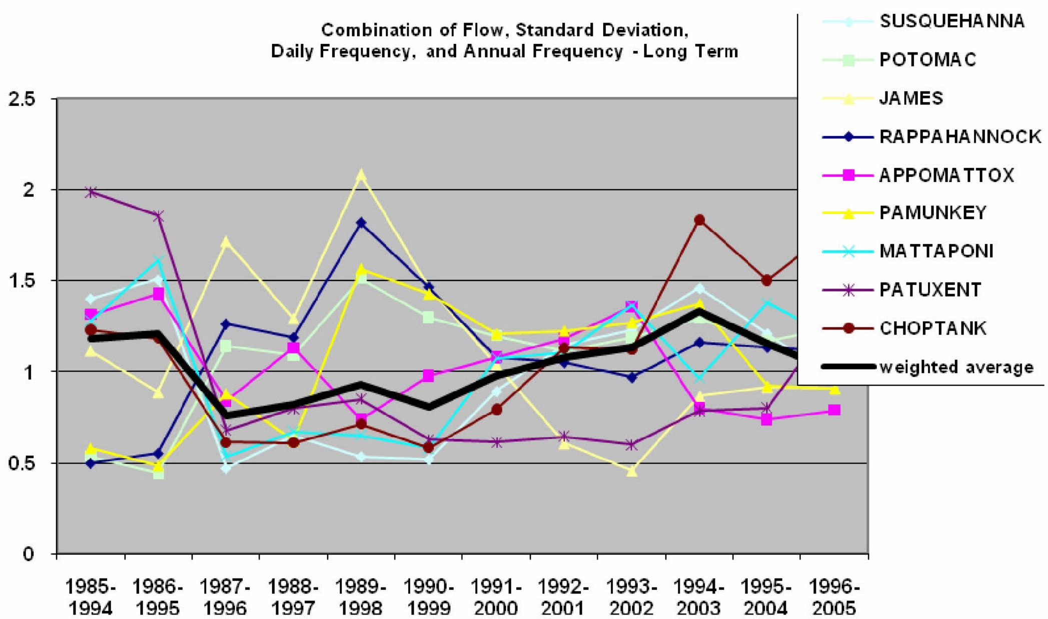


Figure F-2. The combined statistic for the candidate ten-year periods by the nine major river basins for the 30-year flow record (a) and the available long term flow record (b).

In Figure F-2, the statistics are all compared to the average, so the average value is one. Lower values reflect better statistical fit to the long term data set, so values below one are the better candidates for a representative hydrologic period. The thick black line in Figure F-2 is the flow-weighted average of the values for the individual major river basins and, therefore, the best overall indication of statistical fit.

Another consideration is the size of the spread around the flow-weighed average. A tighter distribution means that the good statistical fit holds across all major river basins and it not an unrepresentative hydrologic period for any particular major river basin. The candidate periods

1987-1996, 1988-1997, 1990-1999, and 1991-2000 are all better than average in terms of the statistical fit (Figure F-2). However, the first three candidate periods—1987-1996, 1988-1997, and 1990-1999—all have individual major river basins that are not good statistical fits. The period 1991-2000 has the tightest overall grouping meaning that it is representative across all major river basins (Figure F-2).

The ten-year hydrologic assessment period from 1991 to 2000 was selected for the following reasons:

- It was one of the ten-year periods within the 1985-2005 Chesapeake Bay model simulation period that was closest to an integrated metric of long-term flow.
- Each of the nine major river basins had statistics that were particularly representative of the long-term flow for both the 30 year flow record and available long term flow record.
- It overlaps several years with the previous 2003 tributary strategy allocation assessment period (1985-1994) facilitating comparisons between the two assessments.
- It incorporates more recent years than previous 2003 assessment period (1985 -- 1994).
- It encompasses the complete decade of 1991 to 2000, which is a straightforward span of time to communicate to the public,
- It overlaps with the Chesapeake Bay Water Quality Model calibration period (1993 to 2000), which is important for the accuracy of the model predictions.
- The ten year period encompasses the 3-year critical period (1993-1995) for the Chesapeake Bay TMDL as explained in Section 6.1.2 and documented within Appendix G.